CHAPTER 6 FURTHER APPLICATIONS OF NEWTON'S LAW

Select odd-numbered solutions, marked with a dagger (†), appear in the Student Solutions Manual, available for purchase. Answers to all solutions below are underscored.

†6-1. Pull = $nP_{Egyption}$, where n = number of Egyptians. Assume that the obelisk is being pulled at a constant speed. The total pull must be equal to the kinetic friction force acting on the obelisk: Pull = $f = \mu_k N.$ For an object resting on a horizontal surface (flat ground) with no vertical forces other than gravity and the normal force acting, the normal force N is equal to the object's weight mg. Thus $nP_{Egyption} = \mu_k mg \Rightarrow n = \dfrac{\mu_k mg}{P_{Egyption}} = \dfrac{(0.30)(7000\text{ kg})(9.81\text{ m/s}^2)}{360\text{ N}} = \underline{5.7 \times 10^3}$ $\underline{\text{Egyptians}}$.

6-2. $f_{s,\max} = 4\mu_s N_{bolt} = 4(0.40)(2700\text{ N}) = \underline{4.3 \times 10^3\text{ N}}.$

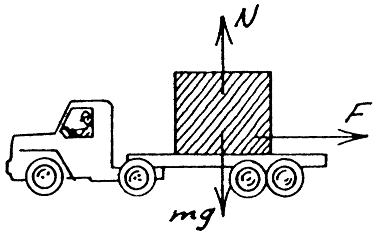
6-3. Let M be mass of automobile.
65 km/hr = 18.06 m/s

$$a = \left|\frac{\frac{1}{2}\left(v^2 - v_0^2\right)}{x - x_0}\right| = \frac{\frac{1}{2}(18.06)^2}{20}\text{m/s}^2 = 8.15\text{m/s}^2$$

But $F = Ma$ where F = frictional force.

$$F = Ma = \mu_s Mg \Rightarrow a = \mu_s g \Rightarrow \mu_s = \frac{a}{g} = \frac{8.15\text{m/s}^2}{9.8\text{m/s}^2} = \underline{0.83}$$

6-4. The force that decelerates the crate is the frictional force between it and the platform of the truck. The frictional force is $F \le \mu_s mg$ (m = mass of crate). When the truck decelerates at a, if the crate is not to slip, there must be a frictional force F so that $F/m = a$. Therefore, at most, $a = F/m \le \mu_s g$.
$a \Rightarrow \mu_s g \Rightarrow 0.4 \times 9.8\text{ m/s}^2 = \underline{3.9\text{ m/s}^2}$

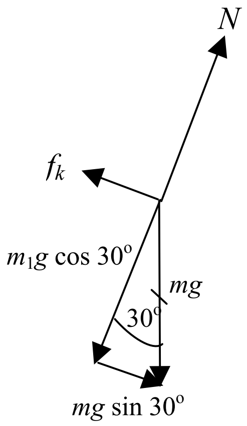


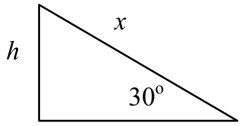
†6-5. Assume that that the car has antilock brakes so it stops without sliding. Then the force between the tire and the road is always the force of static friction. The minimum stopping distance will occur for the largest friction force, which is $f_{s,\max} = \mu_s N.$ On a level surface with no vertical forces acting other than gravity, $N = mg \Rightarrow f_{s,\max} = \mu_s mg.$ The friction force is opposite the motion, so $ma_{dry} = -f_{s,\max} = -\mu_{s,dry} mg \Rightarrow a_{dry} = -\mu_{s,dry} g$. $a_{dry} = \dfrac{v^2 - v_0^2}{2x_{dry}} = -\dfrac{v_0^2}{2x_{dry}}$, which means $\dfrac{v_0^2}{2x_{dry}} = \mu_{s,dry} g.$ For the icy road, $\dfrac{v_0^2}{2x_{icy}} = \mu_{s,icy} g.$ Combining the two equations gives $\dfrac{x_{icy}}{x_{dry}} = \dfrac{\mu_{s,dry}}{\mu_{s,icy}}$, from which we get $x_{icy} = x_{dry}\dfrac{\mu_{s,dry}}{\mu_{s,icy}} = (38\text{ m})\left(\dfrac{0.85}{0.20}\right) = \underline{1.6 \times 10^2\text{ m}}.$

6-6. From Problem 6-5, $\frac{v_0^2}{2x} = \mu_s g$. $v_0 = \sqrt{2\mu_s xg} = \sqrt{2(0.80)(290\text{ m})(9.81\text{ m/s}^2)} = 67.5$ m/s. Convert this to mph: $v = 67.5\frac{\text{m}}{\text{s}} \times \frac{1\text{ mi}}{1601\text{ m}} \times 3600\frac{\text{s}}{\text{h}} = \underline{152\text{ mph}}$!

†6-7. The technique is similar to that outlined in Problem 6-5 except that we use the force of kinetic friction, which means $a = -\mu_k g$. $2ax = v^2 - v_0^2 \Rightarrow x = -\frac{v_0^2}{2a} = \frac{v_0^2}{2\mu_k g}$. v_0 = 10 km/h = 25 m/s $\Rightarrow x = \frac{(25\text{ m/s})^2}{2(0.60)(9.81\text{ m/s}^2)} = \underline{53\text{ m}}$.

6-8. Take the *x* direction to point down the slide and the *y* direction to be normal to the ramp in the free body diagram. There is no motion in the y direction, so the sum of forces in that direction must be zero. The sum of forces in the *x* direction must be equal to ma_x: $\sum F_y = N - mg\cos 30° = 0$, $\sum F_x = mg\sin 30° - f_k = ma_x$. Using $f_k = \mu_k N$, solving the *y* equation for *N*, and substituting into the *x* equation gives $ma_x = mg\sin 30° - \mu_k mg\cos 30°$, or $a_x = g(\sin 30° - \mu_k\cos 30°) = (9.81\text{ m/s}^2)[\sin 30° - (0.15)\cos 30°] =$ 3.63 m/s^2. Call *h* the height of the slide. The total distance traveled along the slide is $x = \frac{h}{\sin 30°} = \frac{3.5\text{ m}}{\sin 30°} = 7.0$ m. Since the initial speed is zero, the speed at the end of the slide will be $v = \sqrt{2a_x x} = \sqrt{2(3.63\text{ m/s}^2)(7.0\text{ m})} = \underline{7.2\text{ m/s}}$.





†6-9. $f_k = \mu_k N \Rightarrow a = -\frac{f_k}{m} = -\frac{\mu mg}{m} = -\mu g$, where the – sign means the acceleration points in the opposite direction from the velocity. Since the player is on level ground with no vertical forces other than gravity and the normal force acting, $N = mg$. $\mu k = 0.30 \Rightarrow a = -(0.30)(9.81\text{ m/s}^2) = -2.94\text{ m/s}^2$. The distance required for him to stop is $x = \frac{v^2 - v_0^2}{2a} = \frac{0-(4.5\text{ m/s})^2}{2(-2.94\text{ m/s}^2)} =$ 3.4 m. Since he only has to slide 2.8 m to reach home, he will easily reach the plate. His speed when he reaches the plate will be $v = \sqrt{v_0^2 + 2ax} = \sqrt{(4.5\text{ m/s})^2 + 2(-2.94\text{ m/s}^2)(2.8\text{ m})} = \underline{1.9\text{ m/s}}$.

6-10. $f_{s,\max} = \mu_s N = \mu_s mg \Rightarrow \mu_s = \frac{f_{s,\max}}{mg}$. $m = 2.33\frac{\text{g}}{\text{cm}^3} \times (10 \times 10^{-6}\text{ m})^3 \times \left(\frac{10^2\text{ cm}}{\text{m}}\right)^3 \times \left(\frac{10^{-3}\text{ kg}}{\text{g}}\right)$ $= 2.33 \times 10^{-12}$ kg. $\mu_s = \frac{0.5 \times 10^{-9}\text{ N}}{(2.33 \times 10^{-12}\text{ kg})(9.81\text{ m/s}^2)} = \underline{22}$.

6-11. For an object sliding on a horizontal surface with no downward forces acting except gravity,

$$|a| = \frac{|f_k|}{m} = \frac{\mu_k N}{m} = \frac{\mu_k mg}{m} = \mu_k g \Rightarrow \mu_k = \frac{|a|}{g}.\ \left|\frac{\Delta v}{\Delta t}\right| = \left|\frac{v - v_0}{\Delta t}\right| = \frac{35\text{ m/s}}{7.5\text{ s}} = 4.67\text{ m/s}^2.$$

$$\mu_k = \frac{4.67\text{ m/s}^2}{9.81\text{ m/s}^2} = \underline{0.48}.$$

6-12. $f_{air} = \dfrac{C\rho A v^2}{2}$. $f_{road} - f_{air} = ma \Rightarrow f_{road} = f_{air} + ma$. At constant speed, $a = 0$, and $f_{road} = f_{air}$.

$\dfrac{C\rho A}{2} = \dfrac{(0.35)(1.3\text{ kg/m}^3)(3.4\text{ m}^2)}{2} = 0.7735$ kg/m. At 20 m/s, $f_{road} = (0.7735\text{ kg/m})(20\text{ m/s})^2 =$ $\underline{3.1\times 10^2\text{ N}}$. If the speed is doubled to 40 m/s, the force is quadrupled: $f_{road} = 4(3.1\times 10^2\text{ N}) = \underline{1.2\times 10^3\text{ N}}$.

†6-13. The net horizontal force acting on the car is $f_{road} - f_{air} = ma \Rightarrow f_{road} = ma + f_{air} = ma + \dfrac{C\rho A v^2}{2}$.

Substituting the numerical data from the problem,

$$f_{air} = (900\text{ kg})(2.0\text{ m/s}^2) + \frac{(0.30)(1.3\text{ kg/m}^3)(2.8\text{ m}^2)(25\text{ m/s})^2}{2} = \underline{2.1\times 10^3\text{ N}}.$$

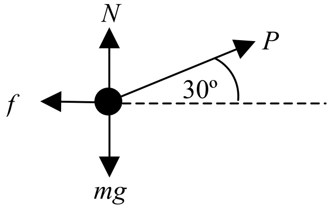
6-14. At terminal speed v_T, the upward drag force equals the downward weight of the falling object.

$$\frac{C\rho A v_T^2}{2} = mg \Rightarrow v_T = \sqrt{\frac{2mg}{C\rho A}} = \sqrt{\frac{2mg}{C\rho\pi r^2}} = \sqrt{\frac{2(2.5\times 10^{-3}\text{ kg})(9.81\text{ m/s}^2)}{(0.51)(1.3\text{ kg/m}^3)(\pi)(1.6\times 10^{-2}\text{ m})^2}} = \underline{9.6\text{ m/s}}.$$

6-15. For a sphere, $v_T = \sqrt{\dfrac{2mg}{C\rho\pi r^2}} \Rightarrow C = \dfrac{2mg}{\pi\rho r^2 v_T^2} = \dfrac{2(0.045\text{ kg})(9.81\text{ m/s}^2)}{(\pi)(1.3\text{ kg/m}^3)(0.02\text{ m})^2(45\text{ m/s})^2} = \underline{0.27}.$

6-16. $v_T = \sqrt{\dfrac{2mg}{(CA)\rho}} = \sqrt{\dfrac{2(70\text{ kg})(9.81\text{ m/s}^2)}{(0.42\text{ m}^2)(1.3\text{ kg/m}^3)}} = \underline{50\text{ m/s}}.$

†6-17. A free body diagram for the sled is shown. P is the pull exerted by the girl, m is the mass of the sled, N is the normal force exerted by the ground on the sled, and f is the kinetic friction force between the sled and the ground. Take x to point right and y to point up. Then $\sum F_y = N + P\sin 30° - mg = 0$ because the sled does not move in the y direction.



$\sum F_x = P\cos 30° - f = 0$ because the sled is being pulled at constant velocity. From the equation for $\sum F_y$, $N = mg - P\sin 30°$. From the equation for $\sum F_x$, $P\cos 30° - f = P\cos 30° - \mu_k N = P\cos 30° - \mu_k N = 0$. Thus

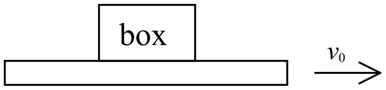
$P\cos 30° - \mu_k(mg - P\sin 30°) = 0$, which gives $P = \dfrac{\mu_k mg}{\cos 30° + \mu_k \sin 30°}$

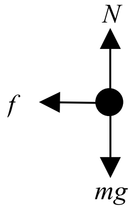
$$\underline{= \frac{(0.60)(40\text{ kg})(9.81\text{ m/s}^2)}{\cos 30° + (0.60)\sin 30°} = 2.0\times 10^2\text{ N}.}$$

6-18. The maximum frictional force between the driving wheels and the track = $\mu_s mg$ (mg is the weight on the driving wheels). $\mu_s mg = m_{total}a$. $a = \dfrac{\mu_s mg}{m_{total}} = \dfrac{(0.25)(1.36\times10^5\text{ kg})(9.81\text{ m/s}^2)}{(2.00\times10^5 + 100\times1.80\times10^3)\text{ kg}}$

$= \underline{0.88\text{ m/s}^2}$.

†6-19. "Deceleration" is a nontechnical way of saying that the speed of the truck is decreasing. That means the magnitude of the velocity is decreasing. Suppose the truck's initial velocity was to the right (+ x) as shown. If it is slowing down, then its acceleration must point to the left ($-x$). If the box doesn't slide on the back of the truck, then it must always be at rest relative to the truck and must have the same acceleration as the truck. If the box is sliding, that means its acceleration is different from the truck's. The free body diagram for the box shows that there are only three forces acting on it: its weight mg, a normal force N, and a friction force f between it and the truck. To determine the direction of the friction force, suppose there was no friction between the box and the truck. Then when the truck began to slow down, the box would continue moving to the right at its original speed. That means the friction force must point to the left as shown in the diagram. This is very important: *There is no horizontal force in the direction of motion*!





The vertical forces add to zero, so $N = mg$. The box is sliding, so f is a force of kinetic friction. Since f is the only horizontal force acting, $-f = -\mu_k N = ma_x$. Since $N = mg$, this gives $a_x = -\mu_k g = -(0.50)(9.81\text{ m/s}^2) = -4.91\text{ m/s}^2$. The acceleration of the box relative to the truck is $\mathbf{a}' = \mathbf{a}_x - \mathbf{a}_{truck}$, which gives $a' = -4.91\text{ m/s}^2 - (-7.0\text{ m/s}^2) = 2.01\text{ m/s}^2$. (The + sign means the box is moving to the right relative to the truck.) If the box slides a distance x along the back of the truck, then its speed relative to the truck is given by $(v')^2 - (v')_0^2 = 2a'x$, where $v_0' = 0$ because the box was initially at rest relative to the truck (it was moving with the same velocity as the truck). Thus $\underline{v' = \sqrt{2ax} = \sqrt{2(2.01\text{ m/s}^2)(2.0\text{ m})} = 2.8\text{ m/s.}}$

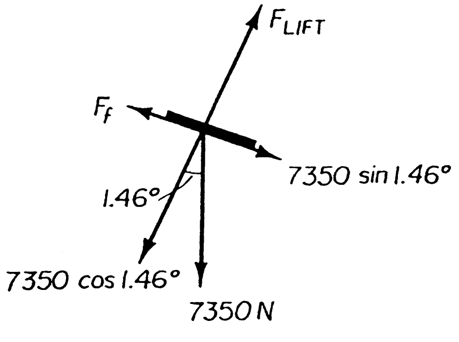
6-20. 35 knots = $\dfrac{35\times1.852}{3.6}$ = 18 m/s

Therefore, the angle of descent

$\theta = \sin^{-1}\dfrac{0.46}{18} = 1.46°$

$F_f = 7350\sin 1.46° = \underline{188\text{ N}}$

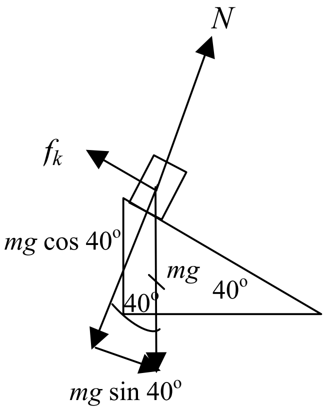
$F_{LIFT} = 7350\cos 1.46° = \underline{7348\text{ N}}$



6-21. Force of gravity (along direction of road) must equal total frictional force. $F = mg\sin\theta = 500$ N, where θ is the angle of the road to the horizontal $\sin\theta = \dfrac{500}{1.5\times10^3\times9.8} = 0.0340$

$\underline{\theta = 1.9°}$

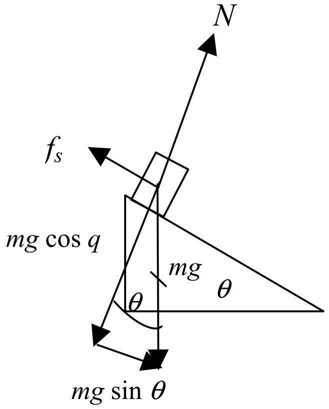
6-22. Choose the *x* axis to point down the slope and the *y* direction to point up and normal to the slope. Then $\sum F_y = N - mg\cos 40° = 0$, $\sum F_x = mg\sin 40° - f_k = ma_x$. Using $f_k = \mu_k N$, solving the *y* equation for *N*, and substituting into the *x* equation gives $ma_x = mg\sin 40° - \mu_k mg\cos 40°$, or $a_x = g(\sin 40° - \mu_k\cos 40°) = (9.81\text{ m/s}^2)\left[\sin 40° - (0.10)\cos 40°\right]$ = 5.55 m/s^2. 130 kph = 36.1 m/s. $x = \dfrac{v^2 - v_0^2}{2a} = \dfrac{(36.1\text{ m/s})^2 - 0}{2(5.5\text{ m/s}^2)} =$ 117 m. Final result = $\underline{1.2 \times 10^2\text{ m}}$. $t = \dfrac{v - v_0}{a} = \dfrac{36.1\text{ m/s} - 0}{5.55\text{ m/s}^2} = \underline{6.5\text{ s}}$.



†6-23. A free body diagram is shown. As the plate is tilted, the block remains at rest as the static friction force increases from zero (at zero elevation) to its maximum value of $\mu_s N$ at some angle θ, and then the block begins to slide. At θ, since the block is at rest, the sums of forces along the plate and perpendicular to the plate are

$$N = mg\cos\theta$$
$$\mu_s N = mg\sin\theta$$

Dividing the second equation by the first gives $\mu_s = \dfrac{\sin\theta}{\cos\theta} = \tan\theta$. For $\theta = 38°$, $\underline{\mu_s = 0.78}$.



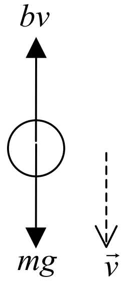
6-24. $v_T = \sqrt{\dfrac{2mg}{C\rho_{air}A}} = \sqrt{\dfrac{2\left(\dfrac{4\pi\rho_{steel}r^3}{3}\right)g}{C\rho_{air}\pi r^2}} = \sqrt{\dfrac{8\rho_{steel}rg}{3C\rho_{air}}}$. The terminal speed is proportional to the square root of the ball's radius, so proportional reasoning can be used:

$$\frac{v_{T,\,5\text{ cm}}}{v_{T,\,0.25\text{ cm}}} = \sqrt{\frac{(5\text{ cm})}{(0.25\text{ cm})}} \Rightarrow v_{T,\,5\text{ cm}} = (88\text{ m/s})\sqrt{50} = \underline{3.9 \times 10^2\text{ m/s}}.$$

†6-25. At terminal speed, $a = 0$, which means viscous drag force = weight $\Rightarrow bv_T = mg$.

$$v_T = \frac{mg}{b} = \frac{(3.9\times10^{-9}\text{ kg})(9.81\text{ m/s}^2)}{2.8\times10^{-5}\text{ kg/s}} = \underline{1.4 \times 10^{-3}\text{ m/s (1.4 mm/s)}}.$$

6-26. Choose the + direction to point down. Newton's Second Law gives $\sum F = mg - bv = ma = m\dfrac{dv}{dt} \Rightarrow \dfrac{dv}{dt} = g - \dfrac{bv}{m}$. Rearrange and integrate: $\displaystyle\int_0^v \frac{dv}{\left(g - \dfrac{bv}{m}\right)} = \int_0^t dt$. Either look up the integral in a table or use the substitution $u = g - \dfrac{bv}{m}$ to do the integration directly. The result is $-\dfrac{m}{b}\ln\left(g - \dfrac{bv}{m}\right)\Bigg|_0^v = t$, which

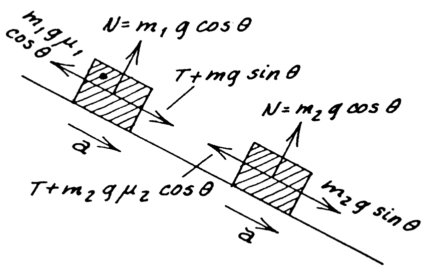


becomes $\ln\left(\frac{g-\frac{bv}{m}}{g}\right)=-\frac{bt}{m}$. Taking the antilog of both sides gives $g-\frac{bv}{m}=ge^{-\frac{bt}{m}}$. Rearranging gives v: $\underline{v=\frac{mg}{b}\left(1-e^{-\frac{bt}{m}}\right)}$. Note that this goes to mg/b as $t \to \infty$, in agreement with the result in Problem 6-25. The characteristic time is the time required for the speed to reach $(1-e^{-1})v_T$, which is $t_{characteristic} = m/b$. For the data in Problem 6-25, this is $t_{characteristic}=\frac{3.9\times10^{-9}\ \text{kg}}{2.8\times10^{-5}\ \text{kg/s}}=$ $\underline{1.4\times10^{-4}\ \text{s}\ (0.14\ \text{ms})}$.

†6-27. Recall that $f_k=\mu_k N$. On a level road with no vertical forces acting except gravity, $N = mg$, so $a_{level} = -\mu_k g$ if friction is the only horizontal force acting. On a slope of angle θ, $N = mg\cos\theta$. If the car is initially moving down the slope, then there is a component of the car's weight pointing down the slope and the friction force points up the slope. Taking the + direction to be downward (in the direction of the initial velocity), then the acceleration along the slope is $a_{slope}=g(\sin\theta-\mu_k\cos\theta)$. If the car is going to slow down, the acceleration must be negative (point in the opposite direction from the initial velocity). For the slope, this means $\mu_k\cos\theta>\sin\theta$, or the car won't be able to slide to a stop. For both cases, use $v^2=v_0^2+2ax$ with v_0 = 90 kph = 25 m/s and $v = 0$. Assume μ_k is the same on the level road and the slope. Solve for a on the level road and use that to find μ_k, then find a and x on the slope. Level road: $a_{level}=-\frac{v_0^2}{2x_{level}}=-\frac{(25\ \text{m/s})^2}{2(35\ \text{m})}=-8.93\ \text{m/s}^2$. $\mu_k=-\frac{a_{level}}{g}=\frac{8.93}{9.81}=$ 0.910. For a 1:10 slope, $\theta=\tan^{-1}\frac{1}{10}=5.71°$. $a_{slope}=(9.81\ \text{m/s}^2)[\sin5.71°-(0.910)\cos5.71°]=-7.91\ \text{m/s}^2$.

$x_{slope}=-\frac{v_0^2}{2a_{slope}}=\frac{(25\ \text{m/s})^2}{2(7.91\ \text{m/s}^2)}=$ $\underline{39.5\ \text{m}}$.

6-28. Construct a free-body diagram as shown.



$T + m_1 g\sin\theta - m_1 g\,\mu_1\cos\theta = m_1 a$ (1)

$-T + m_2 g\sin\theta - m_2 g\,\mu_2\cos\theta = m_2 a$ (2)

Adding (1) + (2) gives

$(m_1+m_2)g\sin\theta - g(\mu_1 m_1+\mu_2 m_2)\cos\theta$
$= (m_1+m_2)a$

$$\Rightarrow a=\frac{g}{(m_1+m_2)}\,[(m_1+m_2)\sin\theta-(\mu_1 m_1+\mu_2 m_2)\cos\theta]$$

$$=\frac{9.81}{2.0+2.0}(4.0\sin50°-[0.60(2.0)+0.40(2.0)]\cos50°)\ \text{m/s}^2=\underline{4.4\ \text{m/s}^2}$$

$T = m_1(a = g\,\mu_1\cos\theta - g\sin\theta)$ from (1)

$= 2.0(4.36 + 9.81(0.60)\cos50° - 9.8\sin50°)\ \text{N} = \underline{1.3\text{N}}$

6-29. (b) $N = F\sin\theta$ (i)

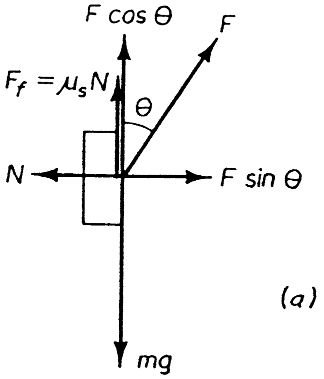
$\mu_s N + F\cos\theta = mg$ (ii)

from (i) and (ii)

$$F = \frac{mg}{\mu_s \sin\theta + \cos\theta}$$

(c) $\dfrac{\partial F}{\partial\theta} = -mg\left(\dfrac{\mu_s\cos\theta - \sin\theta}{(\mu_s\sin\theta + \cos\theta)^2}\right)$

$= 0$ if $\mu_s\cos\theta - \sin\theta = 0$ or $\underline{\theta = \tan^{-1}\mu_s}$

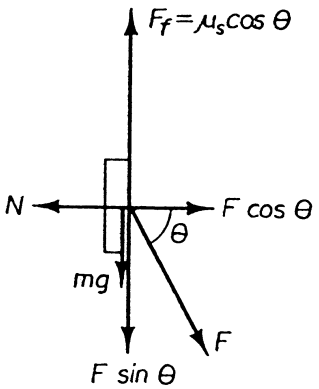


(d) $\mu_s F\cos\theta = mg + F\sin\theta$

$$F = \frac{mg}{\mu_s\cos\theta - \sin\theta}$$

for $\theta = \tan^{-1}\mu_s$

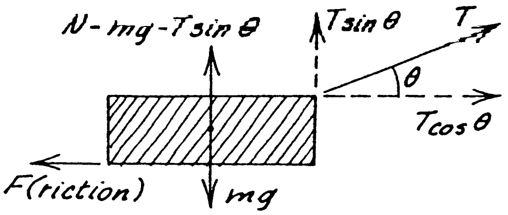
F $\longrightarrow \infty$ and it will become impossible to hold the book.



6-30. Forces shown on free-body diagram. Normal force $N = mg - t\sin\theta$. Frictional force $F = \mu_k N = \mu_k (mg - T\sin\theta)$. To keep the box moving at constant velocity the net force = 0. Therefore $F = T\cos\theta \Rightarrow \mu_k(mg - T\sin\theta) = T\cos\theta \Rightarrow \mu_k mg = T(\cos\theta + \mu_k\sin\theta) \Rightarrow T = \mu_k mg[\cos\theta + \mu_k\sin\theta]^{-1}$ $\dfrac{dT}{d\theta} = -\mu_k mg[\cos\theta + \mu_k\sin\theta]^{-2}[-\sin\theta + \mu_k\cos\theta] = 0$ at minimum tension This condition is fulfilled at $-\sin\mu + \mu_k\cos\theta = 0$ $\underline{\Rightarrow \tan\theta = \mu_k}$.

$$T = \frac{\mu_k mg}{\cos\theta + \mu_k\sin\theta} = \frac{\mu_k mg}{\dfrac{1}{\sqrt{1+\mu_k^2}} + \dfrac{\mu_k^2}{\sqrt{1+\mu_k^2}}}$$

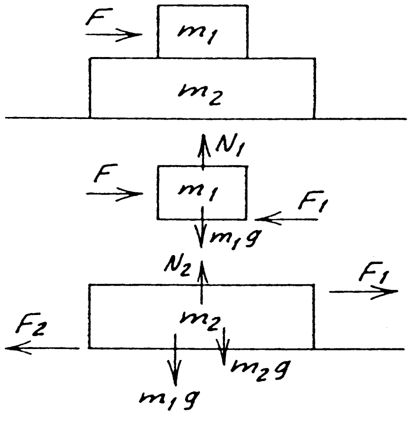
$$\underline{= \frac{\mu_k mg}{\sqrt{1+\mu_k^2}}}$$



†6-31. In Example 3, change the angle from 30° to some arbitrary value θ. Then requirement for the minimum magnitude of P is $P\cos\theta - \mu_k P\sin\theta - \mu_k mg = 0$, or $P(\cos\theta - \mu_k\sin\theta) - \mu_k mg = 0$. If $\cos\theta - \mu_k\sin\theta < 0$, then both terms in the equation will be negative and it will not be possible to find a value for P that satisfies the equation. If $\mu_k\sin\theta - \cos\theta > 0$, the crate will not move no matter how hard it is pushed. This can be rewritten as $\mu_k\sin\theta > \cos\theta$, or $\tan\theta > \dfrac{1}{\mu_k}$, or

$$\underline{\theta > \tan^{-1}\left(\frac{1}{\mu_k}\right)}.$$

6-32. Let F_1, F_2 be frictional forces of masses as shown.
$F_1 = \mu_1 N_1 = \mu_1 m_1 g$. $F_2 = \mu_2 N_2 = \mu_2(m_1 + m_2)g$



Acceleration of masses:

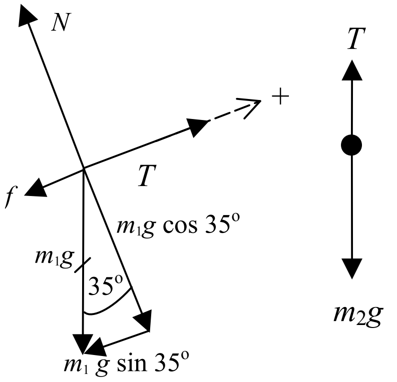
$$m_1 : a = \frac{\text{Net Force}}{m} = \frac{F - F_1}{m_1}$$

$$= \frac{F - \mu_1 m_1 g}{m_1} = \underline{F/m_1 - \mu_1 g}$$

$$m_2 : a = \frac{F_1 - F_2}{m_2} = \frac{\mu_1 m_1 g - \mu_2(m_1 + m_2)g}{m_2}$$

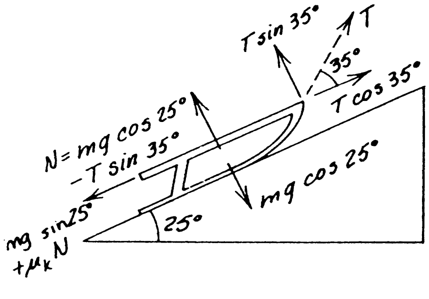
$$= \underline{\frac{g}{m_2(\mu_1 m_1 - \mu_2[m_1 + m_2])}}$$

†6-33. Free body diagrams for the two masses are shown. Let the tension on the string be T. Take the $+x$ direction for m_1 to point up the ramp. For m_2, take the + direction to point up. The sum of forces perpendicular to the ramp is zero because there's no motion in that direction. Thus $N = m_1 g\cos 35°$. The magnitude of the kinetic friction force is $\mu_k N$,so the sum of forces along the x direction is $T - \mu_k m_1 g\cos 35° - m_1 g\sin 35° = m_1 a_1$. For m_2, the sum of forces gives $T - m_2 g = m_2 a_2$. If m_2 moves down, then m_1 must move up the ramp. Thus the accelerations a_1 and a_2 must have opposite signs. If the string connecting them doesn't stretch and has negligible mass, then the accelerations must have the same magnitude. Thus we conclude that $a_2 = -a_1$, which we'll just call a. Then the two force equations become $T - m_1 g(\sin 35° + \mu_k\cos 35°) = m_1 a$ and $m_2 g - T = m_2 a$. Adding the two equations eliminates T and gives $a = \frac{g[m_2 - m_1(\sin 35° + \mu_k\cos 35°)]}{m_1 + m_2}$



$$= \underline{\frac{9.81\ \text{m/s}^2[3.0\ \text{kg} - (1.5\ \text{kg})(\sin 35° + 0.40 \times \cos 35°)]}{4.5\ \text{kg}} = 3.6\ \text{m/s}^2}.$$

6-34. Let the pull of the man be T.
Then the free-body diagram is as shown. This means for constant velocity, the net force along the incline = 0. Therefore



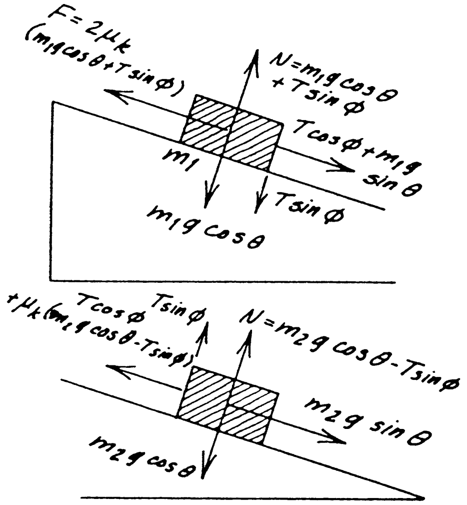
$mg\sin 25° + \mu_k N = T\cos 35°$

$\Rightarrow mg \sin 25° + \mu_k (mg \cos 25° - T \sin 35°) = T \cos 35°$

$\Rightarrow T(\cos 35° + \mu_k \sin 35°) = mg(\sin 25° + \mu_k \cos 25°)$

$$T = \frac{mg(\sin 25° + \mu_k \cos 25°)}{\cos 35° + \mu_k \sin 35°} = \frac{80 \times 9.8(\sin 25° + 0.7\cos 25°)}{\cos 35° + 0.7\sin 35°} = \underline{680\,\mathrm{N}}$$

6-35. Let T be the tension on the string. Let the trailing block have mass m_1, the leading block mass m_2. Draw the free-body diagram. Using $F = ma$ gives



(i) $T \cos \theta + m_1 g \sin \theta$
$- 2\mu_k(m_1 g \cos \theta + T \sin \phi$
$\phi) = m_1 a$

(ii) $m_2 g \sin \theta - \mathrm{T} \cos \phi$
$- \mu_k(m_2 g \cos \theta - T \sin \phi) = m_2 a$

or

(1) $T(\cos \phi - 2\mu_k \sin \phi + m_1 g \sin \theta - 2\mu_k m_1 g \cos \theta = m_1 a$

(2) $T(\mu_k \sin \phi - \cos \phi) + m_2 g \sin \theta - \mu_k m_2 g \cos \theta = m_2 a$

To solve for T multiply (1) by m_2, (2) by m_1

$Tm_2(\cos \phi - 2\mu_k \sin \phi) + m_1 m_2 g \sin \theta - 2\mu_k m_1 m_2 g \cos \theta = m_1 m_2 a$

$Tm_1(\mu_k \sin \phi - \cos \phi) + m_1 m_2 g \sin \theta - \mu_k m_1 m_2 g \cos \theta = m_1 m_2 a.$

Subtracting one from the other gives

$T[m_2(\cos \phi - 2\mu_k \sin \phi) - m_1(\mu_k \sin \phi - \cos \phi)]- \mu_k m_1 m_2 g \cos \theta = 0$

$T(m_2 \cos \phi - 2m_2 \mu_k \sin \phi - m_1 \mu_k \sin \phi + m_1 \mu \cos \phi) = \mu_k m_1 m_2 g \cos \theta$

$\underline{T = (\mu_k m_1 m_2 g \cos\theta)/[(m_1 + m_2) \cos \phi - (m_1 + 2m_2)\mu_k \sin\phi].}$

To solve for a, multiply (1) by $(\cos \phi - \mu_k \sin \phi)$, (2) by $(\cos \phi - 2\mu_k \sin \phi)$

$T(\cos \phi - 2\mu_k \sin \phi)(\cos \phi - \mu_k \sin \phi) + m_1 g \sin \theta (\cos \phi - \mu_k \sin \phi)$
$- 2\mu_k m_1 g \cos \theta (\cos \phi - \mu_k \sin \phi) = m_1(\cos \phi - \mu_k \sin \phi)a$

$- T(\cos \phi - \mu_k \sin \phi)(\cos \phi - 2\mu_k \sin \phi) + m_2 g \sin \theta (\cos \phi - 2\mu_k \sin \phi)$
$- \mu_k m_2 g \cos \theta (\cos \phi - 2\mu_k \sin \phi) = m_2 (\cos \phi - 2\mu_k \sin \phi)a.$

Adding the latter two equations gives

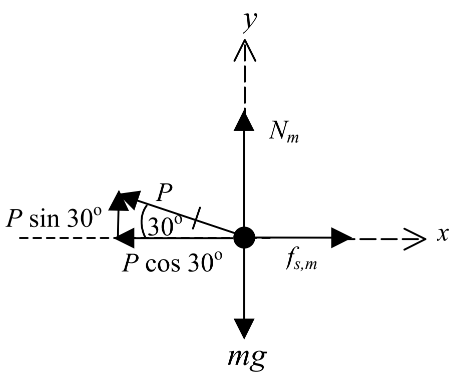
$\Rightarrow m_1 g \sin \theta (\cos \phi - \mu_k \sin \phi) + m_2 g \sin \theta (\cos \phi - 2\mu_k \sin \phi)$
$- 2 \mu_k m_1 g \cos \theta (\cos \phi - \mu_k \sin \phi) - \mu_k m_2 g \cos \theta (\cos \phi - 2\mu_k \sin \phi)$
$= m_1 (\cos \phi - \mu_k \sin \phi)a + m_2 (\cos \phi - 2\mu_k \sin \phi)a$

$\underline{a = g[m_1(\sin\theta \cos\phi - \mu_k \sin\theta \sin\phi - \mu_k \cos\theta \cos\phi + 2\mu_k^2 \cos\theta \sin\phi)]}$

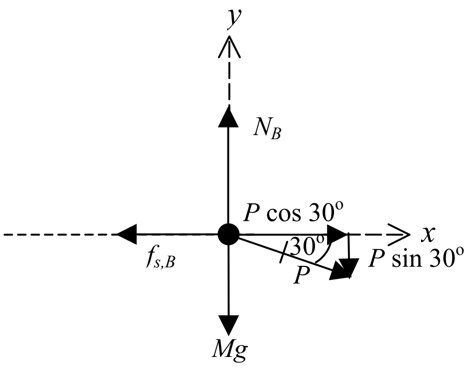
$\underline{+m_2(\sin\theta \cos\phi \; 2\mu_k \sin\theta \sin\phi \, \mu_k \cos\theta \cos\phi + 2\mu_k^2 \cos\theta \sin\phi)]}$

$\underline{+\{m_1(\cos\phi - \mu_k \sin\phi) + m_2(\cos\phi - 2\mu_k \sin\phi)\}.}$

6-36.



man



Box

Free-body diagrams are shown for the man and the box. Note that because of Newton's Third Law, if the man pushes on the box with a force *P* directed towards the right at 30° below horizontal, then the box must push back on the man with a force *P* directed towards the left at 30° above the horizontal. The mass of the box is given as *M*, and the mass of the man is *m*. Since the box is being pushed toward the right, the static friction force on it points to the left. Because the box is pushing toward the left on the man, the static friction force on him points to the right. The normal forces on the man and the box are labeled N_m and N_B, respectively. The diagrams show the resolution of the *P* force into *x* and *y* components. The heaviest box the man can push will result in the largest friction forces acting on the man and the box, so each friction force will be equal to the appropriate coefficient of friction multiplied by the appropriate normal force.

(a) Box: $\sum F_y = N_B - P\sin 30° - Mg = 0;\ \sum F_x = P\cos 30° - f_{s,B} = 0$

Man: $\sum F_y = N_m + P\sin 30° - mg = 0;\ \sum F_x = f_{s,m} - P\cos 30° = 0$

Solve for N_B and use $f_{s,B} = \mu_{s,B} N_B$ to find *P* in terms of *M*: $P = \dfrac{\mu_{s,B} Mg}{\cos 30° - \mu_{s,B}\sin 30°}$. Now solve for N_m and use $f_{s,m} = \mu_{s,m} N_m$: $\mu_{s,m} mg - \mu_{s,m} P\sin 30° - P\cos 30° = 0.$ Substitute the expression for *P* gotten from the equations for the box: $\dfrac{\mu_{s,B} Mg(\cos 30° + \mu_{s,m}\sin 30°)}{\cos 30° - \mu_{s,B}\sin 30°} = \mu_{s,m} mg.$ *g* cancels from the equation, which can be solved for *M*: $M = \dfrac{\mu_{s,m}(\cos 30° - \mu_{s,B}\sin 30°)}{\mu_{s,B}(\cos 30° + \mu_{s,m}\sin 30°)} m.$ Now substitute the numerical data: $M = \dfrac{(0.80)[\cos 30° - (0.20)\sin 30°]}{(0.20)[\cos 30° + (0.80)\sin 30°]}(75\text{ kg}) = \underline{182\text{ kg}}.$

(b) If the man is pushing upward on the box, the signs of the sin 30° terms are reversed; nothing else changes in the problem. The equation for the maximum mass becomes $M = \dfrac{\mu_{s,m}(\cos 30° + \mu_{s,B}\sin 30°)}{\mu_{s,B}(\cos 30° - \mu_{s,m}\sin 30°)} m,$ and substituting the numerical data gives M = 622 kg.

†6-37. The force exerted by the spring is $\mathbf{F} = -k\mathbf{x}$, where $\mathbf{x}$ is the displacement of the end of the spring. By Newton's Third Law the force required to change the length of the spring is equal in magnitude and opposite in direction to the force exerted by the spring. Therefore the magnitude of the force required to stretch the spring to twice its length is: $|F| = k|x|$ = 150 N/m × 0.15 m = 23 N.

To compress it to one-half its length, x = (0.15 m)/2 = 0.075 m. The magnitude of this force is $|F| = kx$ = 150 N/m × 0.075 m =11 N.

6-38. Spring constant $\mathbf{k} = F/x$

Force due to gravity = mg

Therefore

$$k = \frac{F}{x} = \frac{mg}{x} = \frac{1.5 \times 9.8}{0.20}\text{ N/m} = \underline{73.5\text{ N/m}}$$

†6-39. In stretching from 6.3 to 1.2 cm, $k = \dfrac{1.0\ \text{N}}{(10.2 - 6.3)\ \text{cm}}$ = 0.26 N/cm = 26 N/m. In stretching from 6.3 to 16.5 cm, $k = \dfrac{2.0\ \text{N}}{(16.5 - 6.3)\ \text{cm}}$ = 0.20 N/cm = 20 N/m. Since k is not constant, the spring does not obey Hooke's Law.

6-40. $$k = \frac{|F|}{\Delta x} = \frac{mg}{\Delta x} = \frac{(70\text{ kg})(9.81\text{ m/s}^2)}{0.16\text{ m}} = \underline{4.3 \times 10^3\text{ N/m}}.$$

6-41. $$k = \frac{|F|}{\Delta x} = \frac{3.5\text{ N}}{0.070\text{ m}} = \underline{50\text{ N/m}}.$$

6-42. $$|F| = k\Delta x = (4.8 \times 10^{-2}\text{ N/m})(2 \times 10^{-11}\text{ m}) = \underline{9.6 \times 10^{-13}\text{ N/m}}.$$

6-43. $$k = \frac{|F|}{\Delta x} = \frac{mg}{\Delta x} = \frac{(0.250\text{ kg})(9.81\text{ m/s}^2)}{2.8 \times 10^{-3}\text{ m}} = \underline{8.8 \times 10^2\text{ N/m}}.$$

6-44. $$k = \frac{|F|}{\Delta x} = \frac{mg}{\Delta x} = \frac{(75\text{ kg})(9.81\text{ m/s}^2)}{2.9\text{ m}} = \underline{2.5 \times 10^2\text{ N/m}}.$$

6-45. $$x = \frac{|F|}{k} = \frac{mg}{k} = \frac{(1500\text{ kg})(9.81\text{ m/s}^2)}{1.4 \times 10^7\text{ N/m}} = \underline{1.1 \times 10^{-3}\text{ m (1.1 mm)}}.$$

6-46. k is the spring constant of the original piece. $|F| = k\,\Delta x$. Now for some $|F|$, the shorter piece stretches 1/3 Δx, the longer 2/3 Δx. Let k_s, k_e be the spring constants for the shorter and longer pieces, respectively.

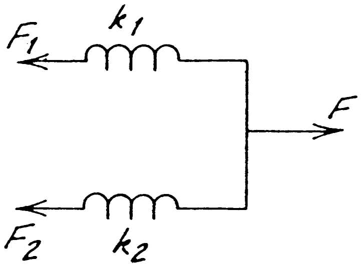
For the shorter piece: $|F| = k_s\left(\frac{1}{3}\Delta x\right) = k\Delta x \Rightarrow \underline{k_s = 3k}$

For the longer piece: $|F| = k_e\left(\frac{2}{3}?x\right) = k\Delta x \Rightarrow \underline{k_e = \frac{3}{2}k}$

Therefore the shorter piece has k_s $\underline{= 360 \text{ N/m.}}$

The longer piece has k_e $\underline{= 180 \text{ N/m.}}$

6-47. Since the springs are in parallel, they both must suffer identical extensions. Let this be x. Let the force due to the spring with constant k_1 be F_1, and that for k_2 be F_2. Then, by Hooke's law, $F_1 = k_1 x$, $F_2^1 = k_2 x$. But by Newton's law, $F = F_1 + F_2$. Therefore, $F = F_1 + F_2 = k_1 x + k_2 x = (k_1 + k_2)x$. For the two springs $F = kx$ therefore, $\underline{k_1 + k_2 = k.}$



6-48. Suppose spring 1 stretches Δx_1 and spring 2 stretches Δx_2. The force pulling on the end of each spring is $|F_1| = k_1\Delta x_1$ and $|F_2| = k_2\Delta x_2$, respectively. Assume spring 1 is at the end where the external force F is applied, so $F = F_1$. Then the magnitude of the net force on that spring would be $|F_2 - F|$. If the springs are in equilibrium, then the net force on each must be zero, which means $F_2 = F$. The total stretch of both springs is $\Delta x = \Delta x_1 + \Delta x_2 = \frac{|F|}{k_1} + \frac{|F_2|}{k_2} = |F|\left(\frac{1}{k_1} + \frac{1}{k_2}\right)$, since the forces must be the same. This means the combined springs act like a single spring with an effective force constant given by $\Delta x = \frac{|F|}{k} = |F|\left(\frac{1}{k_1} + \frac{1}{k_2}\right)$, or $\underline{\frac{1}{k} = \frac{1}{k_1} + \frac{1}{k_2}.}$

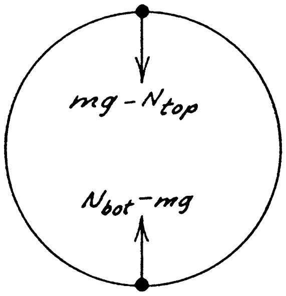
6-49. Let the force that the feet exert on the on the floor be N. Then the force that the floor exerts on the feet (and hence the man) = N. The diagram shows the net force on the man at the top and at the bottom of the ferris wheel.

$v = \frac{2\pi(30)\,m}{60\,\text{s}}$ = 3.14 m/s. So that with $F = mv^2/r$, we have

$F = 80 \times 3.14^2/30 = 26.3$ N

At top: $mg - N_{\text{top}} = F$; $N_{\text{top}} = mg - F = (9.8 \times 80) - 26$ $= \underline{757\,\text{N}}$

At bottom: $N_{\text{bot}} - mg = F$; $N_{\text{bot}} = mg + F = (9.8 \times 80) + 26$ $= \underline{810\,\text{N}}$



6-50. Centripetal force = mv^2/r ; $v = 2\pi r/T$ (T = period of rotation)

$$F = \frac{mv^2}{r} = \frac{m(2\pi r)^2}{rT^2} = \frac{4\pi^2 mr}{T^2} = \frac{4\pi^2(7.3\times10^{22})\times3.8\times10^8\text{ kg m}}{(27\times24\times60\times60)^2\text{ s}^2} = \underline{2.0\times10^{20}\text{ N}}$$

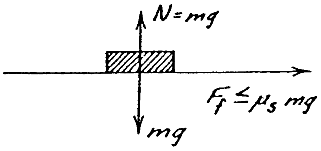
†6-51. The motion described in this problem isn't really uniform circular motion because the woman's speed varies during the swing. However, she is moving in a circular arc, so the centripetal force acting on her at any point is the swing is still given by $F = \frac{mv^2}{r}$, where v is her instantaneous speed . Strictly speaking, the forces acting on the woman are her weight and the normal force exerted by the seat. However, if we neglect the mass of the seat, then the normal force will be the same as the total tension in the two ropes that support the seat. So at the bottom of the swing, the net vertical force acting on the woman is $2T - mg$, which must be the centripetal force at that point: $2T - mg = \frac{mv^2}{r} \Rightarrow T = m\frac{v^2+gr}{2r}$. The radius is the length of the rope (5.0 m), and her speed is 5.0 m/s, so $T = (60\text{ kg})\frac{(5.0\text{ m/s})^2 + (9.81\text{ m/s}^2)(5.0\text{ m})}{2(5.0\text{ m})} = \underline{4.4\times10^2\text{ N}}$.

6-52. The condition for not sliding is that the maximum force of friction,

$F_f = \mu_s mg \Rightarrow F = \frac{mv^2}{r}$ or $v \le \sqrt{\mu_s rg}$

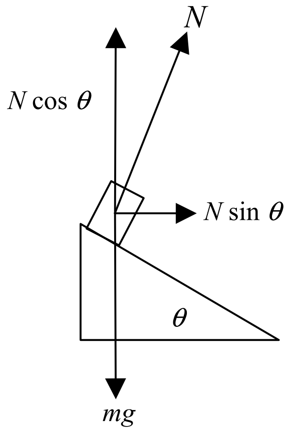
At $v = \sqrt{\mu_s rg} = \sqrt{0.5\times90\times9.8} = \underline{21\text{m/s}}$

the coins will start to slide (the frictional force will be inadequate to keep the coins accelerating towards the center with the car).

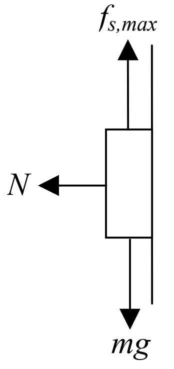


†6-53. The net force in the vertical direction is zero because the car doesn't move in that direction. However, the net horizontal force cannot be zero because a centripetal force is needed to make the car go in a circle. That force comes from the horizontal component of the normal force. From the free-body diagram, $N\cos\theta = mg$, $N\sin\theta = mv^2/r$. (Note that even though the diagram looks very much like one for an object on an inclined plane, the motion being described is quite different and requires a different approach to the analysis.) Dividing the second equation by the first gives $\tan\theta = \frac{v^2}{rg}$. The required speed is 75 kph = 20.8 m/s. Then

$$\theta = \tan^{-1}\left(\frac{v^2}{rg}\right) = \tan^{-1}\left(\frac{(20.8\text{ m/s})^2}{(400\text{ m})(9.81\text{ m/s}^2)}\right) = \underline{6.3°}$$

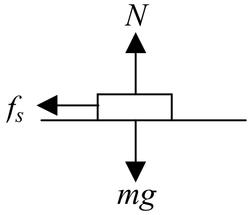


6-54. The normal force N provides the centripetal force keeping the rider moving in a circle. The minimum value of N is the one for which the static friction force is at its maximum value $\mu_s N$. If the rider doesn't slide down, then $f_{s,max} = mg = \mu_s N$. Since N is the centripetal force, $N = \dfrac{mg}{\mu_s} = \dfrac{mv^2}{r} \Rightarrow v = \sqrt{\dfrac{rg}{\mu_s}}$ is the minimum linear speed the rider must have not to slide down.

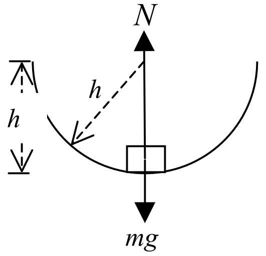


$v = \sqrt{\dfrac{(6.0\text{ m})(9.81\text{ m/s}^2)}{0.25}} = 15.3\text{ m/s}$. Let T stand for the time for one complete revolution. The rider travels through one circumference in time T, so $T = \dfrac{2\pi r}{v} = \dfrac{2\pi(6.0\text{ m})}{15.3\text{ m/s}} = 2.46\text{ s}$, from which we get a rotation frequency $f = \dfrac{1}{T} = \underline{0.41\text{ rev/s}}$.

†6-55. Static friction provides the centripetal force that keeps the ant moving in a circle. The maximum force the surface can exert will occur at the maximum distance the ant reaches before sliding, which is $f_{s,max} = \mu_s N = \mu_s mg = \dfrac{mv^2}{r_{max}}$. The speed is the circumference of the circle divided by the time T for one revolution, and T is the reciprocal of the revolution rate $f \Rightarrow v = \dfrac{2\pi r}{T} = 2\pi rf$. Combining all these gives $r_{max} = \dfrac{\mu_s g}{4\pi^2 f^2} = \dfrac{(0.30)(9.81\text{ m/s}^2)}{4\pi^2(45\text{ rev/min})^2\left(\dfrac{1\text{ min}}{60\text{ s}}\right)^2} = \underline{0.13\text{ m}}$ $\underline{(13\text{ cm})}$.



6-56. When the skateboarder is at the bottom, the net vertical force must provide the centripetal acceleration. Thus $N - mg = \dfrac{mv^2}{h}$, where h is the radius of the circle. According to the hint, $v = \sqrt{2gh}$, so $N = mg + \dfrac{m(2gh)}{h} = 3mg$. $\underline{\text{The normal force is 3 × the weight}}$.



†6-57. The time T for one complete orbit is 24 h = 8.64×10^4 s, and the satellite's speed is the circumference of its orbit divided by T. The "weight" is the centripetal force, so

$$w = \frac{mv^2}{r} = \frac{m\left(\frac{2\pi r}{T}\right)}{r} = \frac{4\pi^2 mr}{T^2} = \frac{4\pi^2(1\text{ kg})(4.23\times 10^7\text{ m})}{(8.64\times 10^2\text{ s})^2} = \underline{0.224\text{ N}}.$$

6-58. This is analogous to a car going around a banked curve. The horizontal component of the normal force provides the centripetal acceleration, and the vertical component of the normal force balances the passenger's weight:

$$N\sin\theta = \frac{mv^2}{r}$$

$$N\cos\theta = mg$$

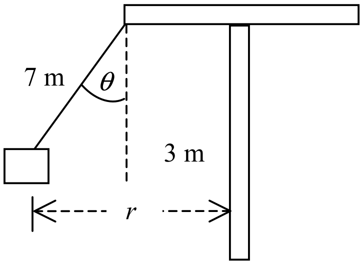
Divide the top equation by the bottom: $\theta = \tan^{-1}\left(\frac{v^2}{gr}\right) = \tan^{-1}\left[\frac{(140\text{ m/s})^2}{(9.81\text{ m/s}^2)(6.0\times 10^3\text{ m})}\right] = \underline{18°}$.

†6-59. The vertical component of the tension in the cable balances the weight of the rider, and the horizontal component provides the centripetal acceleration. Call the mass of the rider m and the cable tension T. Then

$T\sin\theta = \frac{mv^2}{r}$; $T\cos\theta = mg$, where v is the tangential speed of the rider. Dividing the first equation by the second gives $\tan\theta = \frac{v^2}{gr}$. The radius r is (3 + 7sin θ) m, so

$$\frac{v^2}{g(3+7\sin\theta)} = \tan\theta. \text{ This gives } v = \sqrt{g\tan\theta(3+7\sin\theta)}.$$

For θ = 35°, v = $\underline{6.9\text{ m/s}}$.



6-60. For the cars to travel at maximuim speed without skidding

$$F_s = \mu_s mg = \frac{mv_A^2}{R_A} = \frac{mv_B^2}{R_B}$$

Therefore, $\frac{v_A^2}{v_B^2} = \frac{R_A}{R_B}$

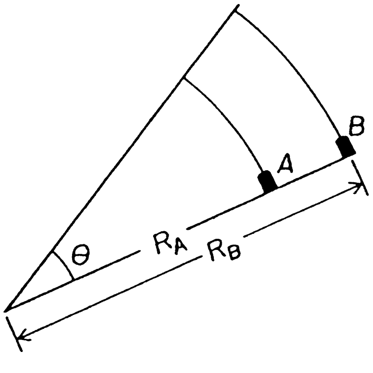
since $R_A < R_B$, $\underline{v_A < v_B}$

Time taken by the two cars to travel through the curved paths

$$t_A = \frac{R_A\theta}{v_A} = \left(\frac{R_A\theta}{v_A^2}\right)v_A$$

$$t_B = \frac{R_B\theta}{v_B} = \left(\frac{R_B\theta}{v_B^2}\right)v_B$$

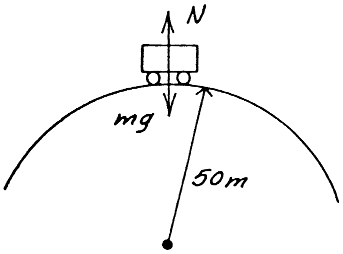
Since the quantities in brackets are equal and $V_A < V_B$, $t_A < t_B$, therefore $\underline{\text{car A emerges from the curve first.}}$



6-61. The net force on the car is $mg - N$ downward where N = normal force of road on car. At the speed where the car just loses contact with the road, $N = 0$, so that $mg = mv^2/r$

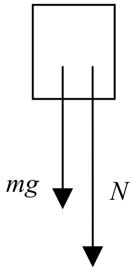
$\Rightarrow v^2/r = g$ or $v = \sqrt{gr} = \sqrt{9.8 \times 50 \text{ m/s}}$

$= \underline{22 \text{ m/s} = 80 \text{ km/hr}}$



6-62. If the water is moving fast enough to stay in the bucket at the highest point in the swing, the bucket will be pushing down on the water with a normal force N. The total force, which is the centripetal force, at the top will be $N + mg = \frac{mv^2}{r}$. At the minimum speed, $N = 0$ at the top. (If the speed is less than this, N will go to zero before the top, which means the water is not touching the bottom of the bucket—it's falling out.) Thus

$$mg = \frac{mv_{min}^2}{r} \Rightarrow v_{min} = \sqrt{gr} = \sqrt{(9.81 \text{ m/s}^2)(0.90 \text{ m})} = \underline{3.0 \text{ m/s}}.$$



6-63. 60 mi/hr = 88 ft/s. From the free-body diagram, with N being the normal force acting on the motorcycle (at angle θ with the vertical),

$mg = N\cos\theta \qquad (1)$

centripetal force $= N\sin\theta = \frac{mv^2}{r} \qquad (2)$

$N = \frac{mv^2}{r\sin\theta}$

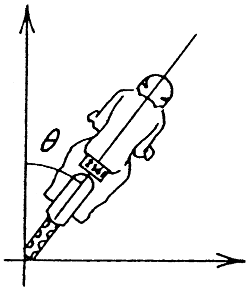
Therefore from (1)

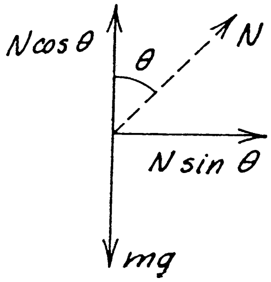
$mg = N\cos\theta = \frac{mv^2}{r\sin\theta}\cos\theta$

$g = \frac{v^2}{r}\cot\theta$

$\tan\theta = \frac{v^2}{gr}$

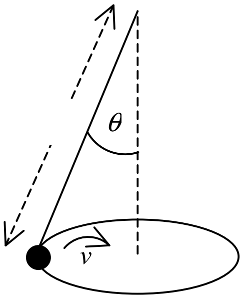
$$\theta = \tan^{-1}\left(\frac{v^2}{gr}\right) = \tan^{-1}\frac{\left(\frac{96}{3.6}\right)^2}{9.8 \times 30} \underline{= 67°}$$

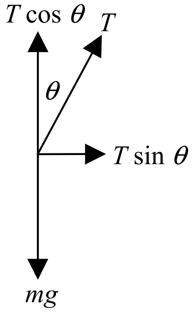




6-64. The maximum friction force is $\mu_s mg$, which gives an acceleration of $a = -\mu_s g$. (The – sign means the acceleration points in the opposite direction from the velocity.) The distance to stop is $x = -\frac{v^2}{2a} = \frac{v^2}{2\mu_s g}$. The radius of the turn required is $r = \frac{v^2}{\mu_s g}$ from Example 10. This is twice the stopping distance, so it's safer for the driver to stop than to attempt the turn.

†6-65. A free body diagram is shown. T is the tension in the string and v is the speed of the ball as it moves in the circle. The sum of forces in the vertical direction is zero, and the horizontal component of the tension provides the centripetal force that keeps the ball moving in its circle. Thus $T\cos\theta = mg$, $T\sin\theta = \frac{mv^2}{r}$, where $r = l\sin\theta$ is the radius of the circle. Divide the second equation by the first: $\frac{\sin\theta}{\cos\theta} = \tan\theta = \frac{v^2}{gr}$. This means the speed of the ball must satisfy $v = \sqrt{gr\tan\theta}$. Substituting for r gives $v = \sqrt{gl\sin\theta\tan\theta}$.





6-66. Let N and F be the normal and frictional forces on the car, respectively. Summing forces horizontally and vertically gives

$N\cos\theta = mg + F\sin\theta$ (1)

$N\cos\theta + F\cos\theta = m(v^2/r) =$ centripetal force (2)

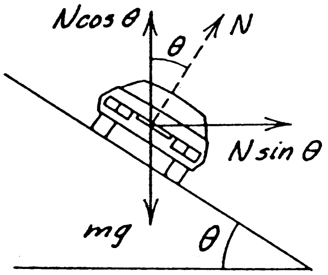
These give

$0.9945\,N - 0.1045\,F = 11760$ (3)

$0.1045\,N + 0.9945\,F = 1875$ (4)

Solving these simultaneously gives

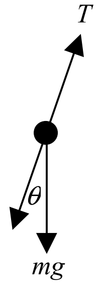
$\underline{N = 1.19\times10^4\,\text{N}}$ $\underline{F = 640\,\text{N}}$



6-67. See Problem 6-58. $\tan\theta = \frac{v^2}{gr} \Rightarrow r = \frac{v^2}{g\tan\theta}$. $v = 320$ kph $= 88.9$ m/s. $r = \frac{(88.9\text{ m/s})^2}{(9.81\text{ m/s}^2)(\tan 30°)} =$ $\underline{1.40\times10^3\text{ m (1.40 km)}}$.

6-68. Both balls must take the same time to go around their respective circles. If we call this time t, then $v_1 = \frac{2\pi r_1}{t}$ and $v_2 = \frac{2\pi r_2}{t}$, which says $v_2 = v_1\frac{r_2}{r_1}$. For m_1, the centripetal force is the tension in the string: $T = \frac{m_1v_1^2}{r_1}$. For m_2, the centripetal force is the horizontal component of the tension: $T\sin\theta = \frac{m_2v_2^2}{r_2}$. Dividing the second equation by the first to eliminate T and using the relation between the speeds gives $\underline{r_2 = r_1\left(\frac{m_1}{m_2}\right)\sin\theta}$.

6-69. When the balls are first released, their instantaneous velocities are both zero. That means the centripetal acceleration of each ball at that instant is equal to zero, so the tension in each string must balance the component of that ball's weight that points along the string. This will be $mg\cos\theta$ for each ball:



$$T - m_1 g\cos\theta_1 = 0$$
$$T - m_2 g\cos\theta_2 = 0$$

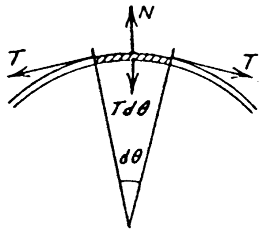
Rewrite each of these with the T on one side of the equal sign and divide one by the other. The result is $\underline{\dfrac{\cos\theta_1}{\cos\theta_2} = \dfrac{m_2}{m_1}}$. Because $m_1 > m_2$, we conclude that $\cos\theta_2 < \cos\theta_1$. That means $\theta_2 > \theta_1$.

When the masses reach the bottom of their swing after being released, $v_2 > v_1$ because both masses take the same time to reach the bottom and m_2 must move farther than m_1. Now for the tension to be the same in both segments of string when the segments are vertical, Newton's Second Law requires

$$T - m_1 g = \frac{m_1 v_1^2}{l}$$
$$T - m_2 g = \frac{m_2 v_2^2}{l}$$

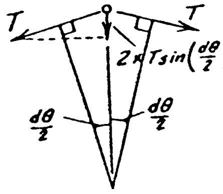
where l is the length of the string. If we subtract the first equation from the second, we get $(m_1 - m_2)g = \dfrac{m_1 v_1^2 - m_2 v_2^2}{l}$. However, this condition can't be satisfied because $m_2 - m_1 > 0$ but $m_1 v_1^2 - m_2 v_2^2 < 0$ since $m_2 > m_1$ and $v_2 > v_1$. Thus it's not possible for these masses to swing without having the heavier one fall down.

6-70. $$-N + 2T\sin\left(\frac{d\theta}{2}\right) = \frac{\sigma R\, d\theta\, v^2}{R}$$



Using $\sin\dfrac{d\theta}{2} \cong \dfrac{d\theta}{2}$

$$N = T\,d\theta - \sigma\, d\theta v^2$$
$$= (T - \sigma v^2)\, d\theta$$

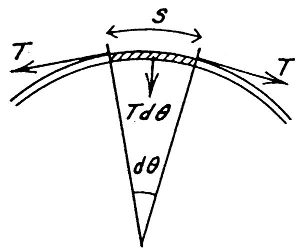


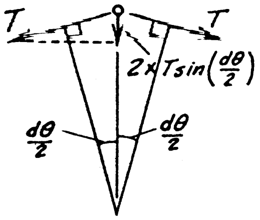
$N = 0$ for $\underline{v = \sqrt{\dfrac{T}{\sigma}}}$

6-71. Take an element of string, making an angle $d\theta$ with the center. Let T be the tension. As shown, the net effect of the tensions at the ends of the element is to produce a net force inward equal to $2\,T\sin(d\theta/2) = T\,d\theta$ because $\sin d\theta/2 \approx d\theta/2$, when $d\theta/2$ is small. Mass of the element is

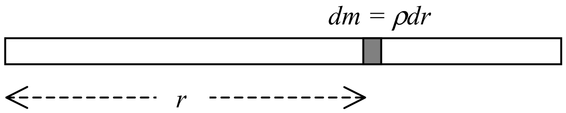
$$\frac{s}{2\pi r}\,m = \frac{r d\theta}{2\pi}\,m = \frac{d\theta}{2\pi}\,m$$

Then $(d\theta/2\pi)m\,v^2/r = T\,d\theta$ gives $\underline{T = mv^2/2\pi r}$





6-72. The speed of a point at a distance r from the hub is $v = \dfrac{2\pi r}{t}$, where t is the time for one complete revolution, 1/320 min. Let ρ = mass per unit length of material. Then the centripetal force required to accelerate element dm at distance r from the hub is



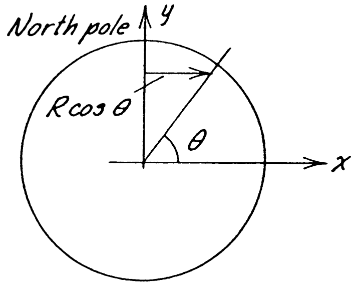
$$dF = \frac{v^2 dm}{r} = \frac{v^2 \rho dr}{r} = \frac{(2\pi)^2 \rho r dr}{t^2}.$$ Therefore the tension is $$T = \int_{r=0}^{r=L} dF = \frac{(2\pi)^2 \rho}{t^2}\int_0^L r dr = \frac{(2\pi)^2 \rho L^2}{2t^2} = \frac{(2\pi)^2 ML}{2t^2}.$$ t = 1/320 min = 0.1875 s, so

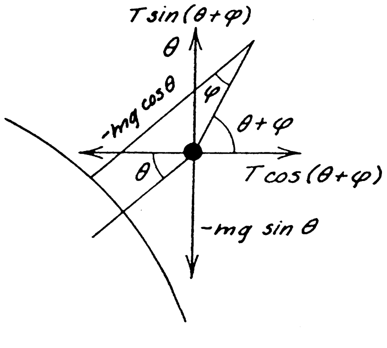
$$T = \frac{2\pi^2 (140\text{ kg})(3.6\text{ m})}{(0.1875\text{ s})^2} = \underline{2.83 \times 10^5\text{ N.}}$$

6-73. Let the x- and y-axes be as shown. Look at a plumb-line at a point at latitude θ. The force due to gravity on the bob is $-mg\cos\theta\,\hat{\mathbf{i}} - mg\sin\theta\,\hat{\mathbf{j}}$

Let the plumb-line be at an angle ϕ to direction of earth's radius as shown. Let the tension on string be T. Then the force on the bob due to the tension on the string is $T\cos(\theta+\phi)\,\hat{\mathbf{i}} + T\sin(\theta+\phi)\,\hat{\mathbf{j}}$

Thus, the net force on the bob is $(T\cos(\theta+\phi) - mg\cos\theta)\,\hat{\mathbf{i}} + (T\sin(\theta+\phi) - mg\sin\theta)\,\hat{\mathbf{j}}$





Thus, the net force on the bob is $(T\cos(\theta+\phi) - mg\cos\theta)\,\hat{\mathbf{i}} + (T\sin(\theta+\phi) - mg\sin\theta)\,\hat{\mathbf{j}}$

The net force in the $\hat{\mathbf{j}}$ direction must be 0, so $T\sin(\theta+\phi) = mg\sin\theta$ (1)

The net force in the $\hat{\mathbf{i}}$ direction must equal the centripetal force. Therefore,

$$-mg\cos\theta + T\cos(\theta+\phi)\,\hat{\mathbf{i}} = -\frac{mv^2}{r}\,\hat{\mathbf{i}}$$

$$= -\frac{m(2\pi R\cos\theta/t)^2}{R\cos\theta}\hat{\mathbf{i}}$$

(t = period of rotation, R = radius of earth)

$$-mg\cos\theta + T\cos(\theta+\phi) = -\frac{m4\pi^2 R\cos\theta}{t^2} \qquad (2)$$

$$\text{(2) gives } T\cos(\theta+\phi) = m\cos\theta\left(g - \frac{4\pi^2 R}{t^2}\right) \qquad (3)$$

(1) divided by (3) gives

$$\tan(\theta+\phi) = \frac{g\tan\theta}{g - \dfrac{4\pi^2 R}{t^2}}$$

$$\phi = \left[\tan^{-1}\left(\frac{g\tan\theta}{g - \dfrac{4\pi^2 R}{t^2}}\right)\right] - \theta = \tan^{-1}\left(\frac{9.81\tan\theta}{9.81 - 4\pi^2\dfrac{6{,}378{,}000}{(24\times60\times60^2)}}\right) - \theta$$

$$= \underline{\tan^{-1}(1.00345\tan\theta) - \theta}$$

At $\theta = 45°$

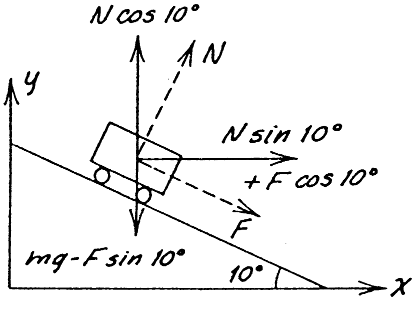
$\phi = \tan^{-1}(1.00345\tan 45°) - 45° = \tan^{-1} 1.00345 - 45° = \underline{0.099°}$

6-74. Draw the free-body diagram, including all forces acting on the car—weight, normal, frictional. The net force on the car is:

$[N\cos 10° - mg - F\sin 10°]\,\hat{\mathbf{j}}$

$+ [N\sin 10° + F\cos 10°]\,\hat{\mathbf{i}}$

But the maximum value for F, which will give the maximum possible speed, is $F = \mu_s N$.



Therefore,

$F_{\text{net}} = [N\cos 10° - mg - \mu_s N \sin 10°]\ \hat{\mathbf{j}} + [N \sin 10° + \mu_s N \cos 10°]\ \hat{\mathbf{i}}$

(at maximum speed)

The net force in the $\hat{\mathbf{j}}$ direction is zero, so that $N(\cos 10° - \mu_s \sin 10°) = mg$

$$N = \frac{mg}{\cos 10° \mu_s \sin 10°} \qquad (1)$$

The force in the $\hat{\mathbf{i}}$ direction must equal the centripetal force:

$$N(\sin 10° + \mu_s \cos 10°) = \frac{mv^2}{r} \qquad (2)$$

Substituting (1) into (2) gives

$$\frac{mg(\sin 10° + \mu_s \cos 10°)}{\cos 10° - \mu_s \sin 10°} = \frac{mv^2}{r}$$

$$v = \left[\frac{rg(\sin 10° + \mu_s \cos 10°)}{\cos 10° - \mu_s \sin 10°}\right]^{1/2} = \sqrt{\frac{120 \times 9.8(\sin 10° + 0.9\cos 10°)}{\cos 10° - 0.9 \sin 10°}}$$

$= \underline{39 \text{ m/s} = 140 \text{ km/hr}}$

†6-75. In Problem 6-60, an equation was derived relating the speed of the mass at the end of the pendulum and the angle the pendulum makes with the vertical. Using the variables in this problem gives $\tan\alpha = \dfrac{v^2}{g(R + l\sin\alpha)}$. However, the speed we need is v_0, which is the speed at a distance R from the center. To figure out v_0 in terms of v, we must recognize that the time for one complete revolution is the same for all parts of the apparatus. This time is the circumference of one of the circles divided by the corresponding speed, so $\dfrac{2\pi R}{v_0} = \dfrac{2\pi(R + l\sin\alpha)}{v}$, from which we get $v = \dfrac{R + l\sin\alpha}{R} v_0$. Then $\tan\alpha = \dfrac{(R + l\sin\alpha)^2 v_0^2}{gR^2(R + l\sin\alpha)} = \dfrac{(R + l\sin\alpha)v_0^2}{gR^2}$, which gives $\underline{v_0^2 = \dfrac{gR^2 \tan\alpha}{R + l\sin\alpha}}$. For the numerical data given, $v_0 = \sqrt{\dfrac{(9.81 \text{ m/s}^2)(0.20 \text{ m})^2(\tan 45°)}{0.20 \text{ m} + (0.30 \text{ m})(\sin 45°)}} = \underline{2.2 \text{ m/s}}$.

6-76. (a) minimum thrust $= 2.45 \times 9.8 \times 10^6 = \underline{2.4 \times 10^7 \text{ N}}$

(b) $3.3 \times 10^7 - 2.4 \times 10^7 = 2.45 \times 10^6\, a$

$$a = \frac{(3.3 - 2.3)10^7}{2.45 \times 10^6} = \underline{3.67 \text{ m/s}^2}$$

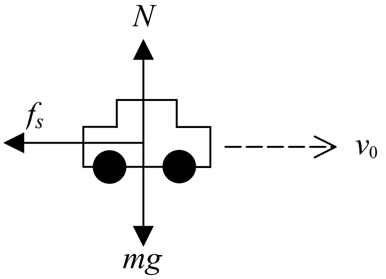
(c) Assuming the thrust is constant during the flight,

$$a = \frac{9 \times 10^6}{0.75 \times 10^6} = \underline{12 \text{ m/s}^2}$$

†6-77. $f_{s,max} = \mu_s N = \mu_s mg.$

$\sum F_x = -\mu_s mg = ma_x \Rightarrow a_x = -\mu_s g.$

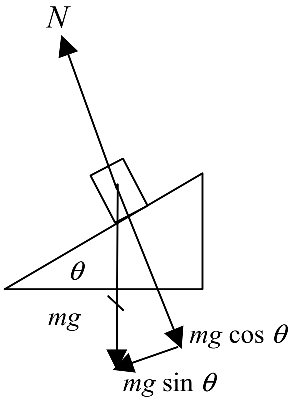
$v^2 - v_0^2 = 2a_x x \Rightarrow x = \dfrac{v^2 - v_0^2}{2a_x} = -\dfrac{v_0^2}{2a_x} = \dfrac{v_0^2}{2\mu_s g}.$ v_0 = 90 kph = 25 m/s.



$$x = \frac{(25\text{ m/s})^2}{2(0.80)(9.81\text{ m/s}^2)} = \underline{40\text{ m}}.$$

$$t = \frac{v - v_0}{a_x} = \frac{v_0}{\mu_s g} = \frac{25\text{ m/s}}{(0.80)(9.81\text{ m/s}^2)} = \underline{3.2\text{ s}}.$$

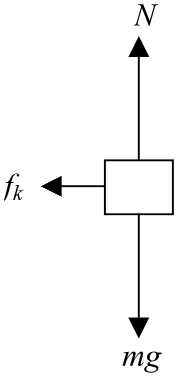
6-78. (a) Take the x direction to point up the slope. If there's no friction, $\sum F_x = -mg\sin\theta = ma_x \Rightarrow a_x = -g\sin\theta.$ The – sign means the acceleration points in the opposite direction from the car's initial velocity. $\theta = \tan^{-1}\dfrac{1}{6} = 9.46°$, so $a_x = -(9.81\text{ m/s}^2)\sin 9.46° = 1.61\text{ m/s}^2$. Final result = $\underline{-1.6\text{ m/s}^2}$.



(b) $v^2 - v_0^2 = 2a_x x \Rightarrow x = \dfrac{v^2 - v_0^2}{2a_x} = -\dfrac{v_0^2}{2a_x}.$ v_0 = 48 kph = 13.3 m/s.

$$x = -\frac{(13.3\text{ m/s})^2}{2(-1.61\text{ m/s}^2)} = \underline{55\text{ m}}.$$

†6-79. (a) The free-body diagram is shown at the right. It is assumed that the initial velocity points to the right (+ x), so the kinetic friction force points left (– x).



(b) $\sum F_y = N - mg = 0 \Rightarrow N = mg = (40\text{ kg})(9.81\text{ m/s}^2) = 392$ N. Final result $\underline{\mathbf{N} = 3.9\times10^2\,\mathbf{j}\text{ N}}$.

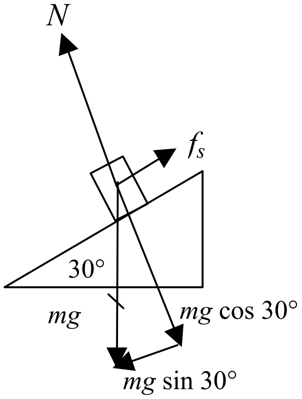
(c) $f_k = \mu_k N = (0.80)(392\text{ N}) = 314$ N. Final result $\underline{\mathbf{f}_k = -3.1\times10^2\,\mathbf{i}\text{ N}}$.

(d) $\mathbf{w} = -mg\mathbf{j} = \underline{3.9\times10^2\,\mathbf{j}\text{ N}}$. $\mathbf{F}_{\mathbf{net}} = \sum F_x\mathbf{i} + \sum F_y\mathbf{j} = -f_k\mathbf{i} = -314\mathbf{i}$ N. Final result $\mathbf{F}_{\mathbf{net}} = \underline{-3.1\times10^2\,\mathbf{i}\text{ N}}$.

(e) $\mathbf{a} = \dfrac{\mathbf{F}_{\mathbf{net}}}{m} = \dfrac{-314\mathbf{i}\text{ N}}{40\text{ kg}} = -7.85\mathbf{i}\text{ m/s}^2$. Final result $\underline{\mathbf{a} = -7.9\mathbf{i}\text{ m/s}^2}$.

$x = \dfrac{v^2 - v_0^2}{2a_x}.$ v_0 = 80 kph = 22.2 m/s. $\underline{x = \dfrac{0 - (22.2\text{ m/s})^2}{2(-7.85\text{ m/s}^2)} = 31\text{ m}}.$

6-80. (a) The free-body diagram is shown. Take the x direction to point up the slope and the y direction to be pointing rightward and normal to the slope (in the direction of N in the diagram).



(b) $\sum F_y = N - mg\cos 30° = 0 \Rightarrow N = mg\cos 30°$

$= (2.0 \text{ kg})(9.81 \text{ m/s}^2)\cos 30°$

= 17.0 N. Final result $\underline{N = 17 \text{ N}}$.

(c) $\sum F_x = f_s - mg\sin 30°$. Since we're told the block is *resting* on the slope, this sum of forces must be zero

$\Rightarrow f_s = mg\sin 30° = (2.0 \text{ kg})(9.81 \text{ m/s}^2)\sin 30°$

= 9.81 N. Final result for this part = $\underline{9.8 \text{ N}}$. As a check, let's verify that this is less than the maximum possible static friction force: $f_{s,max} = \mu_s N = (0.90)(17.0 \text{ N}) = 15.3 \text{ N}$. This is greater than the calculated friction force, so our result of 9.8 N is reasonable.

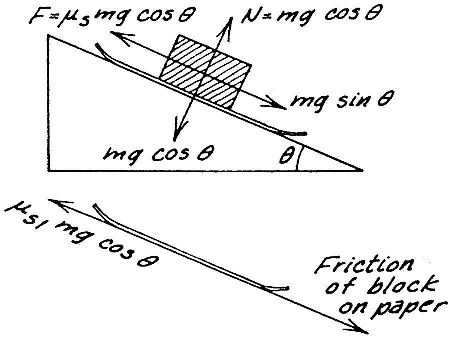
(d) $\mathbf{F}_{\text{plane on box}} = \mathbf{N} + \mathbf{f}_s = \underline{9.81\mathbf{i} + 17.0\mathbf{j} \text{ N}}$. The direction of this force is $\tan^{-1}\dfrac{17.0}{9.81} =$ $\underline{60° \text{ above the slope}}$ or $\underline{90° \text{ above the horizontal}}$.

6-81. Let the spring be compressed Δx. Then, to balance forces
$4k\,\Delta x = mg$ (weight of car)

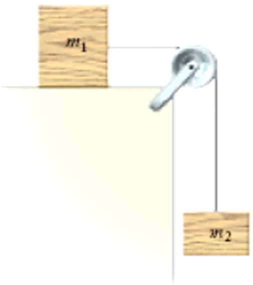
$$\Delta x = \frac{mg}{4k} = \frac{(1200 \times 9.8)\text{N}}{(4 \times 2.0 \times 10^4)\text{N/m}} = \underline{0.15 \text{ m}}$$

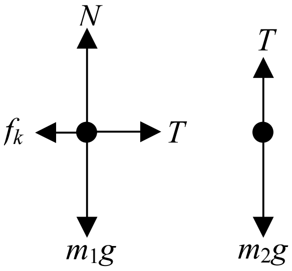
6-82. The paper is, for all practical purposes, massless. The net force on paper always must add to zero. The maximum frictional force of paper on surface is $\mu_s\, mg\cos\theta = 0.5\, mg\cos\theta$. Therefore, the maximum frictional force of the paper on the block = $0.5\, mg\cos\theta$. Block slips (together with paper) when weight force $mg\sin\theta = 0.5\, mg\cos\theta$

$\Rightarrow \underline{\theta = \tan^{-1}(0.5) = 27°}$



†6-83.





(a) Take the x direction to point right and the y direction to point up. Newton's Second Law for m_1 gives $\sum F_y = N - m_1 g = 0$, $\sum F_x = T - f_k = m_1 a_1$. For m_2, $\sum F_y = T - m_2 g = m_2 a_2$. We see that $N = m_1 g \Rightarrow f_k = \mu_k mg \Rightarrow T - m_1 g = m_1 a_1$. If the string passing over the pulley does not stretch, then the magnitude of a_2 must be the same as the magnitude of a_1. If m_1 moves in the $+x$ direction, then m_2 must move in the $-y$ direction, which means $a_2 = -a_1$. Then the equations for $\sum F_x$ for m_1 and $\sum F_y$ for m_2 can be combined to give an equation for a_1: $\underline{a_1 = \dfrac{m_2 - \mu_k m_1}{m_1 + m_2} g}$.

6-84. This is exactly the same as 6-36 but with P at an angle of 0° instead of 30°. We can use either of the equations derived for M from 6-36 with 30° changed to 0°:

$$M = \frac{\mu_{s,m}(\cos 0° - \mu_{s,B}\sin 0°)}{\mu_{s,B}(\cos 0° + \mu_{s,m}\sin 0°)} m = \frac{\mu_{s,m} m}{\mu_{s,B}} = \frac{(0.80)(75 \text{ kg})}{0.20} = \underline{300 \text{ kg}}.$$

†6-85. The wording in the problem implies the springs are in series with one spring hanging from the end of the other. Suppose spring 1 has force constant $k_1 = 2.0 \times 10^3$ N/m and spring 2 has force constant $k_2 = 3.0 \times 10^3$ N/m. Let us further suppose that spring 1 is at the bottom, with the mass m hanging from it. We assume that the mass and the springs are in equilibrium, so the force stretching spring 1 is mg. Then spring 1 stretches Δx_1 because of that force. Spring 1 exerts a force on spring 2 causing it to stretch by Δx_2. If the springs and the mass are in equilibrium, then the net force on each object must be zero. Since there is a force mg pulling down on spring 1, this same force must be pulling on spring 2. Then for each spring, $mg = k_1 \Delta x_1$ and $mg = k_2 \Delta x_2$, respectively. The total stretch of both springs is $\Delta x = \Delta x_1 + \Delta x_2 = \dfrac{mg}{k_1} + \dfrac{mg}{k_2} = mg\left(\dfrac{1}{k_1} + \dfrac{1}{k_2}\right)$.

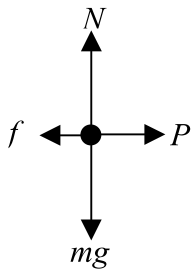
This means the combined springs act like a single spring with an effective force constant given by $\Delta x = \dfrac{mg}{k} = mg\left(\dfrac{1}{k_1} + \dfrac{1}{k_2}\right)$, or $\dfrac{1}{k} = \dfrac{1}{k_1} + \dfrac{1}{k_2}$.

For the springs in this problem, $k = \dfrac{k_1 k_2}{k_1 + k_2} = \dfrac{6 \times 10^6}{5 \times 10^3} \dfrac{\text{N}}{\text{m}} = 1.2 \times 10^3 \dfrac{\text{N}}{\text{m}}$. The magnitude of the total force stretching the "spring" is $mg = (5 \text{ kg})(9.81 \text{ m/s}^2) = 49.1 \text{ N}$. The total stretch of both springs is $\Delta x = \dfrac{|F|}{k} = \dfrac{49.1 \text{ N}}{1.2 \times 10^3 \text{N/m}} = 0.0409 \text{ m } (4.1 \text{ cm})$. The individual stretches are

$$\Delta x_1 = \frac{|F|}{k_1} = \frac{49.1 \text{ N}}{2.0 \times 10^3 \text{N/m}} = \underline{2.5 \text{ cm}}, \text{ and } \Delta x_2 = \frac{|F|}{k_2} = \frac{49.1 \text{ N}}{3.0 \times 10^3 \text{N/m}} = \underline{1.6 \text{ cm}},$$

which do indeed give a total stretch of 4.1 cm to two significant figures.

6-86. (a) If the spring is massless, then the force the spring exerts on the block will be the same as the force exerted on the spring. To start the block moving, the pull P must exceed the maximum static friction force $\mu_s N$. Since the only vertical forces acting are the weight mg and the normal force N, $N = mg = (1.5 \text{ kg})(9.81 \text{ m/s}^2) = 14.7 \text{ N}$ and $f_{s,max} = \mu_s mg = (0.60)(14.7 \text{ N}) = 8.83 \text{ N}$. The stretch of the spring under this force will be



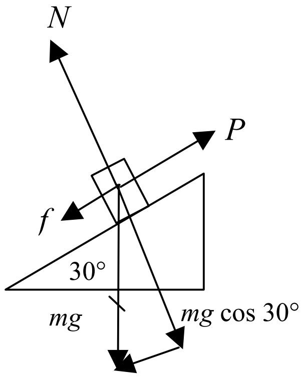
$$\Delta x = \frac{|P|}{k_1} = \frac{14.7 \text{ N}}{1.2 \times 10^3 \text{N/m}} = 7.4 \times 10^{-3} \text{ m } (7.4 \text{ mm}).$$

(b) When the block begins to move, the force changes from static friction to kinetic friction. Take the x direction to point to the right. Then $\sum F_x = P - f_k = P - \mu_k mg = ma_x$, which gives

$$a_x = \frac{P - \mu_k mg}{m} = \frac{8.83\text{ N} - (0.40)(14.7\text{ N})}{1.5\text{ kg}} = 2.0\text{ m/s}^2.$$

(c) "Constant speed" means $a_x = 0$, so $P = \mu_k mg = (0.40)(14.7\text{ N}) = 5.88\text{ N}$. Now the stretch of the spring is $\Delta x = \dfrac{|P|}{k_1} = \dfrac{5.88\text{ N}}{1.2 \times 10^3\text{N/m}} = \underline{4.9 \times 10^{-3}\text{ m (4.9 mm)}}$.

†6-87. (a) If the spring is massless, then the force the spring exerts on the block will be the same as the force exerted on the spring. To start the block moving, the pull P must exceed the total force pointing down the slope, which is the sum of the maximum static friction force $\mu_s N$ and the component of the block's weight parallel to the slope. Adding forces normal to the slope gives $\sum F_y = N - mg\cos 30° = 0 \Rightarrow N = mg\cos 30°$ $= (1.5\text{ kg})(9.81\text{ m/s}^2)\cos 30°$



$= (14.7\text{ N})\cos 30° = 12.7\text{ N}$. Parallel to the slope, $\sum F_x = P - mg\sin 30° - \mu_s N = 0$ $\Rightarrow P = (14.7\text{ N})\sin 30° + (0.60)(12.7\text{ N}) = 15.0\text{ N}$. The stretch of the spring under this force will be $\Delta x = \dfrac{|P|}{k_1} = \dfrac{15.0\text{ N}}{1.2 \times 10^3\text{N/m}} = 1.2 \times 10^{-2}\text{ m (1.2 cm)}$.

(b) When the block begins to move, the force changes from static friction to kinetic friction. Now $P - mg\sin 30° - \mu_k N = ma_x$, which gives $a_x = \dfrac{P - mg\sin 30° - \mu_k N}{m}$.

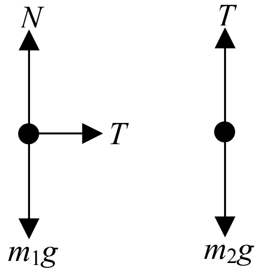
$= \dfrac{15.0\text{ N} - (14.7\text{ N})\sin 30° - (0.40)(12.7\text{ N})}{1.5\text{ kg}} = 1.7\text{ m/s}^2$. The positive result means the acceleration points up the incline.

(c) "Constant speed" means $a_x = 0$, so $P = mg\sin 30° + \mu_k N = 7.34\text{ N} + (0.40)(12.7\text{ N}) = 12.4\text{ N}$.

Now the stretch of the spring is $\Delta x = \dfrac{|P|}{k_1} = \dfrac{12.4\text{N}}{1.2 \times 10^3\text{N/m}} = \underline{1.0 \times 10^{-2}\text{ m (1.0 cm)}}$.

6-88. Free-body diagrams are shown at the right. For m_1, the vertical forces add to zero and the tension in the string provides the centripetal acceleration. For m_2, the net force is zero, so $T = m_2 g$. Thus for m_1, $T = \dfrac{m_1 v^2}{r} = m_2 g \Rightarrow$

$$\underline{v = \sqrt{\frac{m_2 gr}{m_1}}}.$$



6-89. The maximum frictional force, $F_s = \mu_s mg = 0.8\ \text{mg} = 7.84\ \text{m N}$. The centripetal force

$$\frac{mv^2}{R} = \frac{m}{45}\left(\frac{75}{3.6}\right)^2 = 9.64\ \text{m N}$$

Since $\frac{mv^2}{R} > F_s$, the car will skid.

6-90. Centripetal force = mv^2/r; at top of circle, the tension = 0 so the only force on the stone is the weight of the stone = mg. Then $mg = mv^2/r \Rightarrow v = \sqrt{gr}$. Let T be tension on the string at the bottom. Thus

$T - mg$ = centripetal force = $mv^2/r = mg$

Therefore: $T = 2\ mg = 2 \times 0.9 \times 9.8$

$= \underline{17.6\,\text{N}}$